IMPROVED RAIL HAULAGE COMMUNICATIONS

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ABSTRACT

Communications with moving tracked vehicles in a rail haulage mine pose a difficult problem. These communications take place from dispatcher to vehicles or from vehicle to vehicle via the trolley line, which is a very poor communications line. As a result, deadspots and high-signal areas can occur anywhere along the line, or signal can decrease simply as a function of distance.

An analysis is made of the trolley line as a communications line, and methods of improving its characteristics are discussed. Data from inmine experiments are presented, showing actual improvements in communications.

Recent Bureau developments in new hardware are also discussed. These include an adaptive speaker control for existing carrier phones and a new generation of improved carrier phones.

INTRODUCTION

Although trolley carrier phone systems leave much to be desired for haulageway communications, the fact remains that they represent the only practical means of dispatcher-vehicular communications. Most problems associated with these systems are transmission line related; i.e., a trolley line was never intended to be a good communications line, and it certainly is not. However, techniques do exist for improving overall communications. These techniques can be easily implemented, and the results are often excellent.

In addition to the transmission line problem, basic carrier current hardware is archaic in design. Simple improvements can be made to this hardware that make vastly improved communications possible. The most significant improvement is that of incorporating magnetic field pickup instead of voltage pickup on the trolley wire.

COMMUNICATIONS ON THE TROLLEY LINE

Trolley carrier phones presently serve as the most important communication system in rail-haulage mines. These phones are frequency-modulated (FM) transceivers based on tuned radio frequency (TRF) circuitry and usually operate at 88 or 100 kHz, although many other commercially available frequencies are possible. The proper operation of the carrier phone system is essential for both operational and safety reasons. Up to now, there have been no real alternatives to this system for rail vehicular-dispatcher communications. The problems, and sometimes frustrations, of these systems were tolerated simply because there was no alternative.

The usefulness of a trolley carrier phone system stems from its ability to use the trolley line as the transmission path. Since all rail vehicles are physically connected to the trolley line for power, this transmission path is convenient.

However, anyone familiar with mine communications is aware of the fact that trolley carrier phone communications are highly variable in quality. There are times when good communications over great distances are possible. So at best it can be said that trolley carrier phone communications are tolerable, but vast improvements are needed.

The problem, of course, is more of a systems problem than a hardware problem, although improved hardware would certainly help. It is interesting to note that except for changing from vacuum tube circuitry to solid-state circuitry, there have been no basic improvements in the hardware since it was introduced.

The real systems problem is associated with the trolley line itself. Its prime function is to distribute dc power to vehicles and fixed loads. It was never intended to function as a transmission line.

Figure 1 illustrates the theoretical attenuation rate of an unencumbered trolley line functioning as a transmission line, assuming typical values of conductivity of the surrounding medium. The attenuation rate of a carrier phone system operating at 100 kHz is seen to be only 1 db/km. On this basis trolley carrier phones having a dynamic range of 70 db (25 V to 8 mV) should be able to communicate over such a line for 70 km (43 miles). In practice only a small percentage of this range is achieved.

A trolley line, since it is really first and foremost a power bus, is shunted by many mine loads. These loads are vehicle motors, vehicle lights, water pumps, track block lights, personnel heaters, rectifiers, etc. A large rectifier, for example, can have a radio frequency (RF) impedance as low as 2 ohms. When one considers that there can be hundreds of such loads on the trolley line, with some of them being mobile, it becomes apparent why the 70-km range is not achieved.

To learn more about the characteristics of unencumbered trolley lines, measurements were made on such a line in an operating coal mine. These characteristics are as follows:

Characteristic impedance, Z_o	200 ohms
Attenuation rate	1.6 db/km
Inductance/length	1 μH/m
Capacitance/length	30 pf/m
Velocity of propagation	.64 of free space

TRADITIONAL SOLUTIONS

Because of the problems in achieving good communications, several time-honored solutions have been tried to improve things. Perhaps the most widely used solution is the addition of so-called Z-boxes. The Z-box is simply a passive coupling device that permits RF signals to be transferred from one transmission line to another while blocking dc. Tuning is possible to achieve the best signal transfer. The technique is almost always that of transferring signals from a trolley line to a phone line in an attempt to compensate for low signals on the trolley line. In certain instances the approach works well; in other similar instances it can actually degrade communications. Sometimes it only transfers a poor communications area to somewhere else. The addition of Z-boxes to a trolley carrier phone system should be done with caution, because it rarely achieves the desired results. An explanation of this erratic behavior will be offered further in this paper.

When the most important communications link is from dispatcher to vehicles, rather than vehicle to vehicle, good results can often be achieved by connecting the dispatcher's transceiver to a phone line that runs in the same entry as the trolley line. This scheme is often superior to that where the dispatcher is connected to the trolley line also. But, as before, if there are Z-boxes connecting the two, inconsistent results can still occur.

Yet another solution is that of providing the dispatcher with a remote transceiver. In this scheme the transceiver is situated in a favorable location and only the audio and keying lines are run to the dispatcher. This method is especially effective when the dispatcher is located on the surface, or in a remote area of the mine.

One method of reducing the influence of RF shunting loads is to devise a method of isolating those loads. Although the power rectifiers represent the most severe loads on the line, they are often easily improved. Figures 2 and 3 show two possibilities.

If the rectifier is set back far enough from the haulage entry, tuning the leads is often possible. In cases where the leads are too short to exhibit sufficient inductance for tuning, large open air coils can be built and tuned. These and other schemes are discussed in detail in several Bureau of Mines reports.(1) *

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* Numbers in parenthesis refer to References at the end of the paper.

IMPROVED SOLUTION, THE DEDICATED WIRE

The dedicated-wire technique for improving rail haulage communications shows great promise for both rail haulage and whole-mine communications. This technique has been around for some time, although why it worked was not clearly understood.

In the last section, it was shown that coupling to phone lines with Z-boxes, or attaching the dispatcher's transceiver to the phone line, sometimes improves carrier phone communications. This is because a phone line is actually a type of low-grade dedicated wire. It is not as good as a true dedicated wire, because there are phones attached sometimes along with other RF loads. In addition, the phone line has numerous splices, uncontrolled branches, taps, untwisted lengths, etc., that increase attenuation. So the best way to get around this problem is to make sure the dedicated wire is truly dedicated, and that means an independent wire, perhaps 14 gauge, run down the entryway with the trolleyline on the wide side, but not connected to the trolleyline in any manner.

Such a wire, since it is unloaded, has a very low attenuation rate of about 1 db/km (the same as an unloaded trolleyline, since the geometry is the same). Therefore, if a signal is impressed on the dedicated wire, the signal remains high. Since the trolleyline and dedicated wire are located in the same entry, there is a mutual electromagnetic coupling between them. The effects of loads on the trolleyline are transferred to the dedicated wire, and the high signal on the dedicated wire is transferred to the trolleyline. Fortunately, if the separation between the two is large enough, the loading effects of the trolleyline are only weakly transferred to the dedicated wire, so that the attenuation rate stays low. But at the same time, the high signal levels on the dedicated wire are strongly coupled to the trolleyline. The net result is that communication is now possible in areas where it was not possible before.

Figure 4 illustrates the beneficial effects of the dedicated wire in an entryway with a trolleyline. Curve A shows what happens if transmission and reception take place on a dedicated wire only. This is possible between fixed stations but obviously not so if vehicles are involved. Curve B shows the voltage on the dedicated wire, from a transmission on the trolleyline. Curve C shows the reverse, the voltage on the trolleyline from a transmission on the dedicated wire. Curve D shows the signals received on a trolley wire if transmission takes place on the trolley wire.

The theoretical benefits of a dedicated wire to improve trolley carrier phone communications have been proven in practice. In U.S. Steel's Robena mine, a large section of haulageway toward the Willow Tree shaft was such that communication from vehicles to dispatcher was not possible. The solution, suggested by a carrier phone manufacturer, was to install a dedicated wire to the wide side, connected directly to the dispatcher. Z-boxes were also installed, although their benefit is unknown. As a result, good communications was established into an area where it was not possible before.

In Consolidation Coal' Montour #4 mine, the problem was even more serious. A remote dispatcher's transceiver was installed in the offending area, connected to the dispatcher by audio and keying lines. This remote transceiver helped some but not enough. Communications were still poor.

Even connecting the transceiver to the phone line and installing Z-boxes did little to improve the situation. Consol and the Bureau agreed to undertake a carefully controlled experiment to determine whether or not a dedicated wire would be of value.

In November and December 1977, a Bureau team and Consol personnel made measurements in the mine. These measurements were made from a jeep equipped with a Sierra* model 303A tuned voltmeter. The trolley line was encumbered with many loads. Initial measurements without a dedicated line showed that it made little difference if the Z-boxes were connected. However, the installation of a dedicated wire with the dispatcher's remote transceiver connected to it resulted in vast improvements (figure 5) especially in areas of initially low signals. The dedicated wire was properly terminated in 200-ohm resistors, and proper splitting networks were installed at branch points. As a result, communications along the entire entry (several miles) where the dedicated line was installed changed from one of near uselessness to one of good quality.

It should be emphasized that dedicated wire communications is not restricted to the situation where improved trolley wire communications is desired. Indeed, the greatest potential may be in mines that do not even have a trolley line.

One example is Consolidation Coal's Oak Park mine in Eastern Ohio (figure 6). In this mine standard carrier phones are equipped with loop antennas such that they transmit and receive on this antenna instead of by coupling to a trolley wire, which does not exist. This is a belt haulage mine; and the vehicles are used for personnel and supplies. This system permits whole-mine vehicle-to-dispatcher and limited vehicle-to-vehicle communications.

Other mines, such as Repbulic Steel's Kitt mine, are installing similar systems.

MEDIUM-FREQUENCY SYSTEMS

Bureau of Mines research has shown that medium-frequency (MF) (300 kHz to 3 MHz) systems have a very high potential for solving the ultimate problem: Whole-mine communications. Whole-mine communications as described here means the ability for two or more vehicles or personnel to communicate with each other or with a base station, no matter where they are in the mine.

Medium frequencies work well in the mine environment because they are low enough to not suffer severe attenuation while going through conducting mediums but high enough to couple parasitically onto metallic structures in the mine such as power cables or water pipes. Once coupled, linear attenuation on these structures is also low. Several highly controlled measurement programs[3] in the mine environment have been conducted to determine MF characteristics in detail.

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*Use of brand names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

Data so far have shown that in wire-free areas, the determining factor on range is the mine geology, the most favorable of which is low-conductivity coal and high-conductivity overburden and underburden. Under these conditions a parallel-plate waveguide exists, trapping the MF into a cylindrical spreading mode of propagation with low loss. Ranges of up to 350 m were measured under these conditions. In areas containing wires, ranges of many kilometers are not uncommon.

The Bureau is presently designing base stations, repeaters, and portable and vehicular radio to take advantage of the favorable MF propagation modes. The relationship between MF systems and dedicated wire techniques is obvious. A whole mine MF system with base stations and repeaters might be configured as shown in figure 7.

THE LOW-IMPEDANCE LINE

A bridging load R on a transmission line reduces the line voltage to the fraction $\frac{R}{R+Z_o/2}$. Hence, the loss of signal is not only a function of the value of the bridging load R, but also of the characteristic impedance Z_o of the line. It is also apparent that a lower value of Z_o would be beneficial.

Since Z_o for a trolleyline is around 200 to 300 ohms, a convenient way to lower Z_o must be found. For a transmission line, $Z_o = \sqrt{L/C}$. Therefore, one obvious approach would be to add artificial distributed capacitance to the line.

Figures 8 and 9 show an experiment that was recently done to test this low-impedance technique. A 4,460-ft (1.36 km) length of 300-ohm transmission line was deployed on the surface, a signal source was applied, and signal level was measured along the line, first unloaded, and then loaded with three modest loads. The three loads caused a signal loss of 55.5 db, but when 2,000-pf capacitors were attached to the line every 235 ft, only 12.5 db of loss was encountered.

At this writing inmine tests are being planned to determine whether or not this technique can be applied to a mine trolley line. In Consolidation Coal's McElroy mine, a section of trolleyline will be isolated and the characteristic impedance measured. The line will be loaded at various points and signal measurements will be made. The line will then be equipped with shunting capacitors, and the measurements will be repeated. If successful, the low-impedance line technique will be an alternative to the dedicated wire in situations where the installation of the dedicated wire is not desired or practical.

HAULAGEWAY HARDWARE, IMPROVEMENTS AND DEVELOPMENT

As mentioned before, trolley carrier phones have not undergone any basic improvements since they were first developed except for the change from vacuum tube to solid state circuitry. Also there seems to be an industry reluctance to move in the direction of more state-of-the-art circuitry. Whether or not reluctance is justified, there are several simple improvements that can be made to standard carrier phones that are of great value.

Under Bureau contract[4] an improved trolley carrier phone is being developed. Although it is still a simple TRF device, it contains several important different features.

The first feature is that it can receive both in the conventional manner, by voltage pickup from the trolleyline, and also via loop antennas. Inmine measurements have shown that standard carrier phones cannot communicate in the vicinity of heavy RF loads such as rectifiers because the RF voltage on the line is too low. However, RF current and the magnetic field (H-field) are generally high in the vicinity of such loads. Therefore, the situation is complementary. When RF voltage on the trolleyline is low, the current is high, and vice versa. The Bureau carrier phones permit manual selection between voltage pickup and magnetic pickup. A voting circuit could be installed to do this automatically. Inmine tests have consistently shown that magnetic pickup always exceeds voltage pickup, no matter where one is in the mine. It is also a cleaner signal. Because of these findings, there appears to be no reason why a carrier phone even needs RF voltage pickup from the line. Carrier phones with magnetic pickup would likely be extremely immune from dead spots.

Other features that these carrier phones have are phase lock loop FM detection, preemphasis/deemphasis, and a combination conventional-tone squelch circuit.

Another hardware improvement that was evaluated for trolley carrier phone use was an adaptive speaker volume control.[5] Most of the time the adjustment of the volume control on the speaker is a real problem on rail haulage vehicles. When the vehicle is in motion, the noise is so high that the operator sets the volume control to maximum. However, when the vehicle stops, the acoustic environment is very quiet. An incoming message at this vital time can virtually knock one over. Conversely, if the volume control is set low because the vehicle is stopped, failure to turn it up while in motion can be dangerous, for the operator may miss a vital message from the dispatcher or another vehicle.

The adaptive volume control is a small circuit that can be built directly into the speaker housing. A dynamic microphone samples the ambient noise, and a preset level detector activates a relay that applies full power to the speaker if the threshold is exceeded. Otherwise no action takes place and operation is via the volume control. A level detector inhibits the relay drivers from changing the relay setting during the reception of incoming messages, thereby eliminating latchup problems.

CONCLUSION

Several techniques have been discussed concerning ways to improve rail haulage communications. One method concerns using a low-attenuation dedicated wire, preferably not connected to the trolleyline by coupling devices. Strong signals on the dedicated wire couple strongly to the trolleyline, while unfavorable loads on the trolleyline couple only weakly back to the dedicated wire. Another method is to reduce the influence of loads on the trolleyline by lowering the line characteristic impedance. Other solutions have also been included, such as tuning, Z-boxes, use of phone lines, and remote location of the dispatcher's transceiver.

The benefits of medium frequencies were also discussed, and systems based on dedicated wires and medium frequencies were presented.

REFERENCES

1. "Improvements for Mine Carrier Phone Systems," H0346045, A. D. Little, Inc. Final Report available from National Technical Information Service, Springfield, Va. 22161, NTIS No. PB 273 292/AS. 175 pp. $9.

   "Trolley Wire Phone System Guidelines," J0166010, A. D. Little, Inc. Final Report available from National Technical Information Service, Springfield, Va. 22161, NTIS No. PB 273 479/AS. 170 pp. $9.

2. "Propagation of EM Signal in Underground Mines," Collins Radio Division, Rockwell International. Final Report, distribution pending.

3. "Improved Hardware for Trolley Wire Phone Systems," H0166144, Gai-Tronics Corporation. Pending report.

4. "Adaptive Speaker Control for Mine Carrier Phones," J0377098, A. D. Little Inc. Pending report.

THEORETICAL ATTENUATION RATE FOR TYPICAL TROLLEY WIRE/RAIL

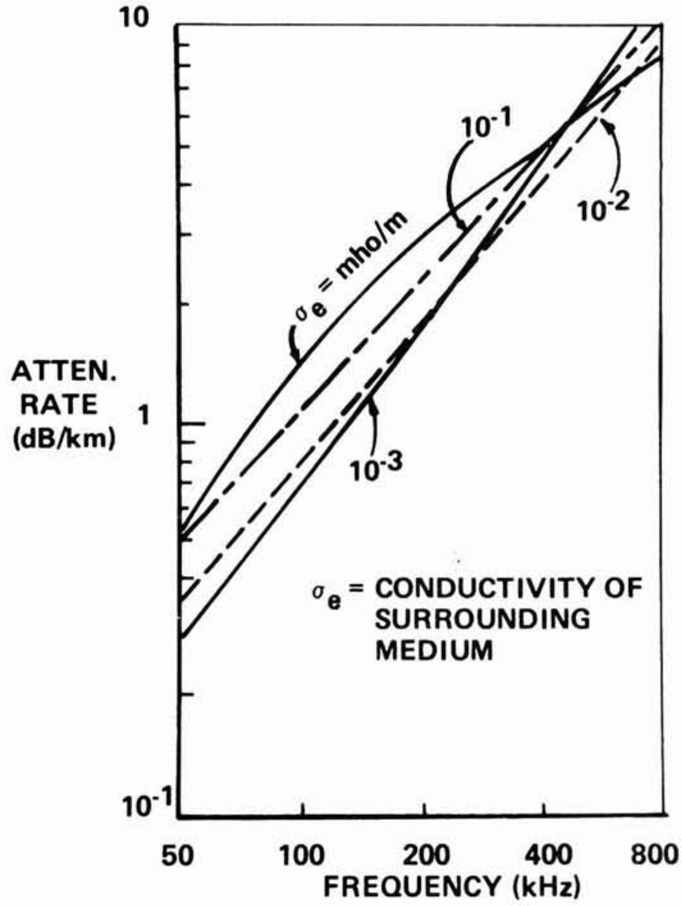

FIGURE 1.--Theoretical Attenuation rate for an unencumbered trolleyline

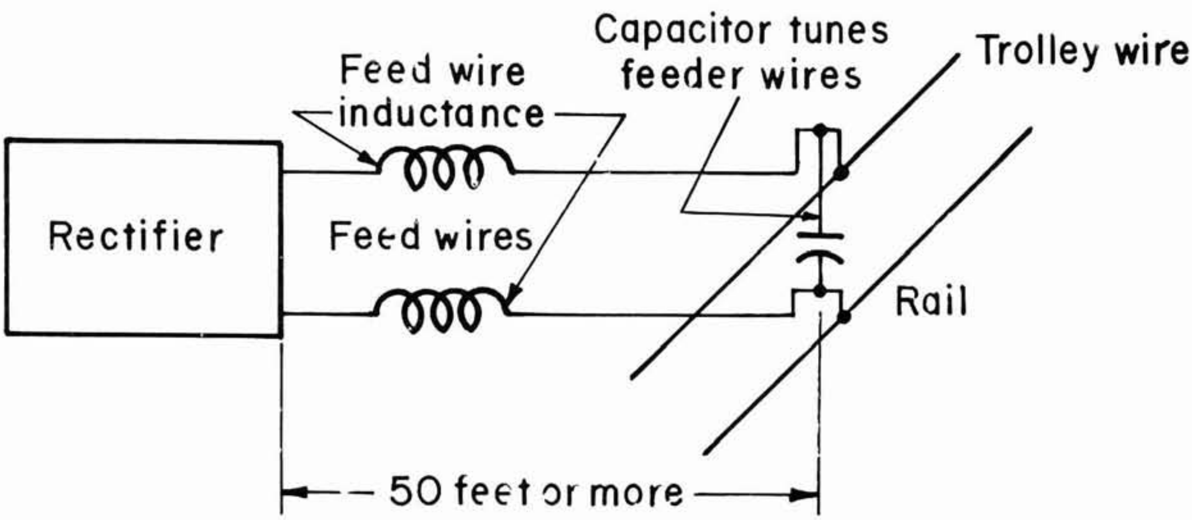

FIGURE 2.--Isolating a rectifier by tuning the feed wire inductance.

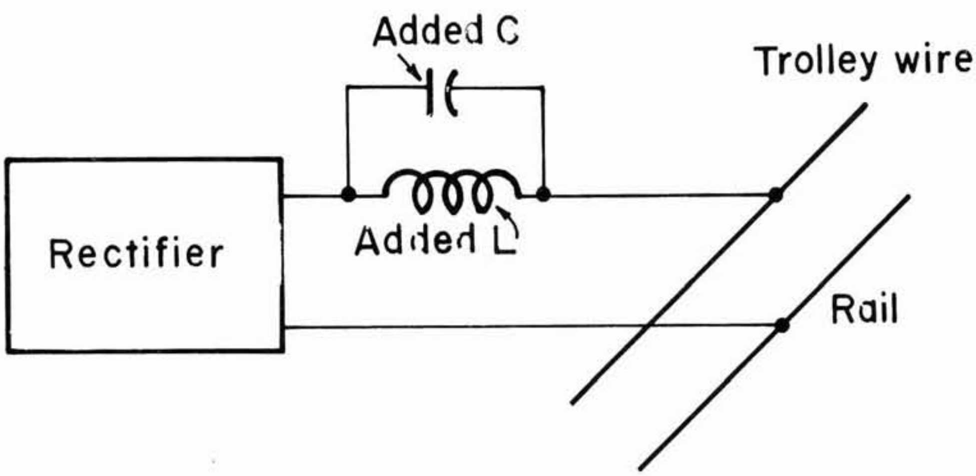

FIGURE 3.--Isolating a rectifier by adding L and C.

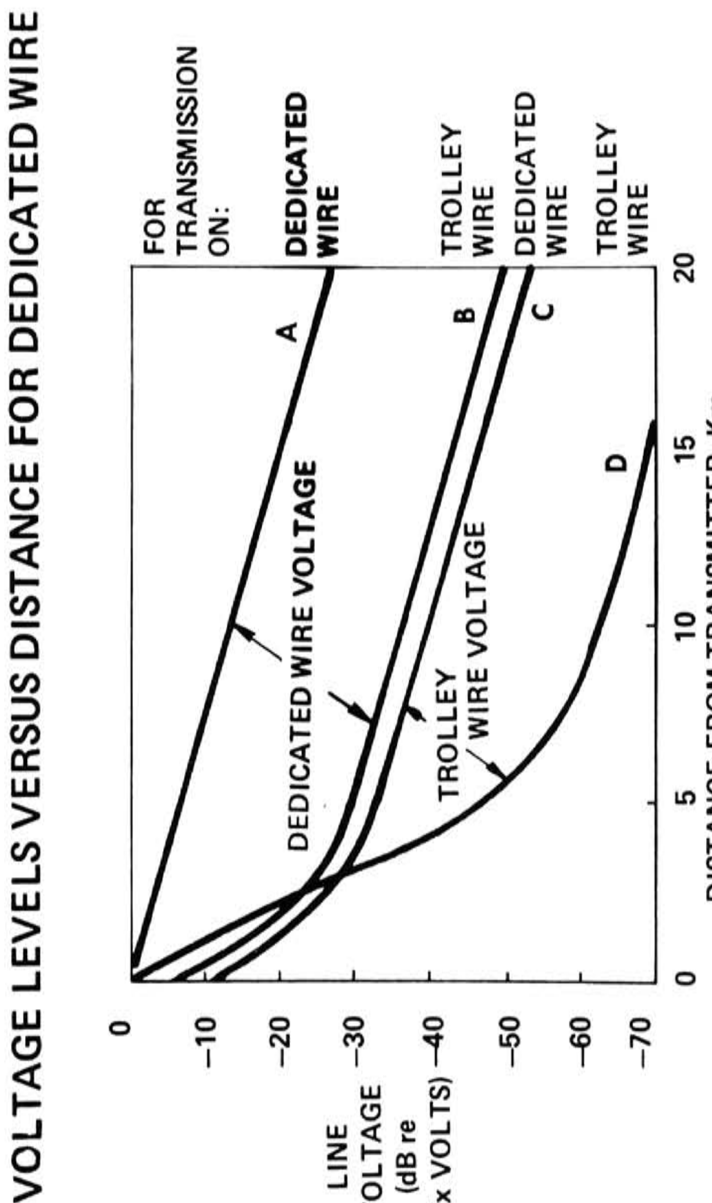

FIGURE 4.--Signal and distance for a dedicated wire.

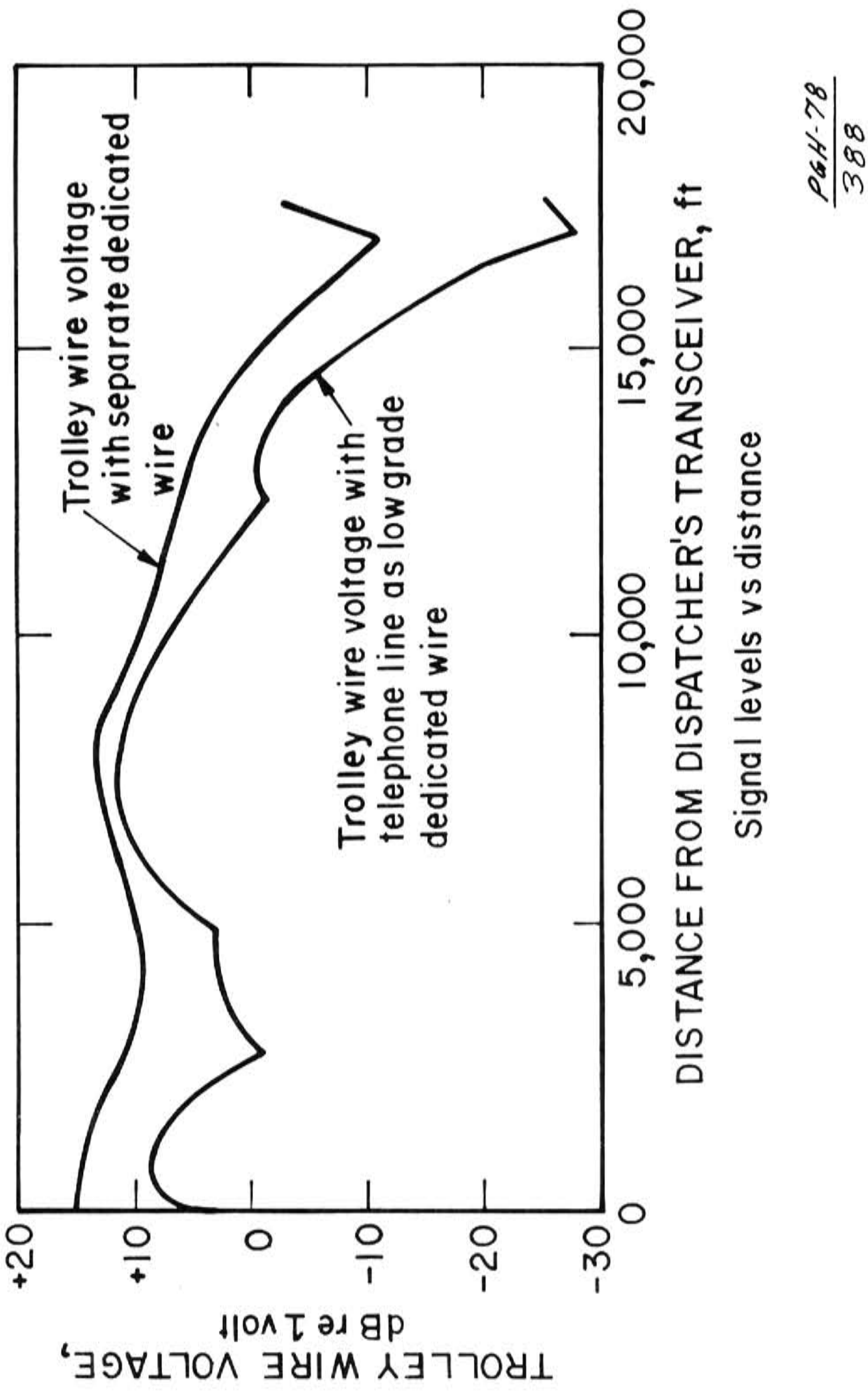

FIGURE 5.--Signal level versus distance with and without dedicated wire.

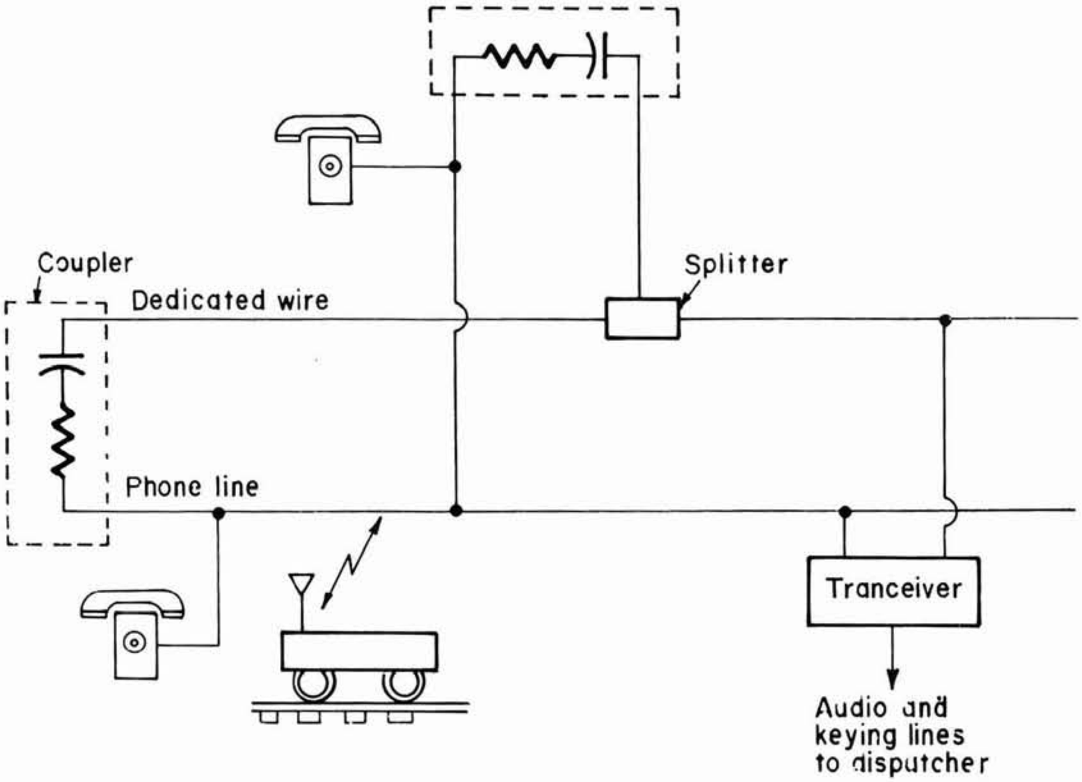

FIGURE 6.--Dedicated wire system for communicating with battery-powered rail vehicles.

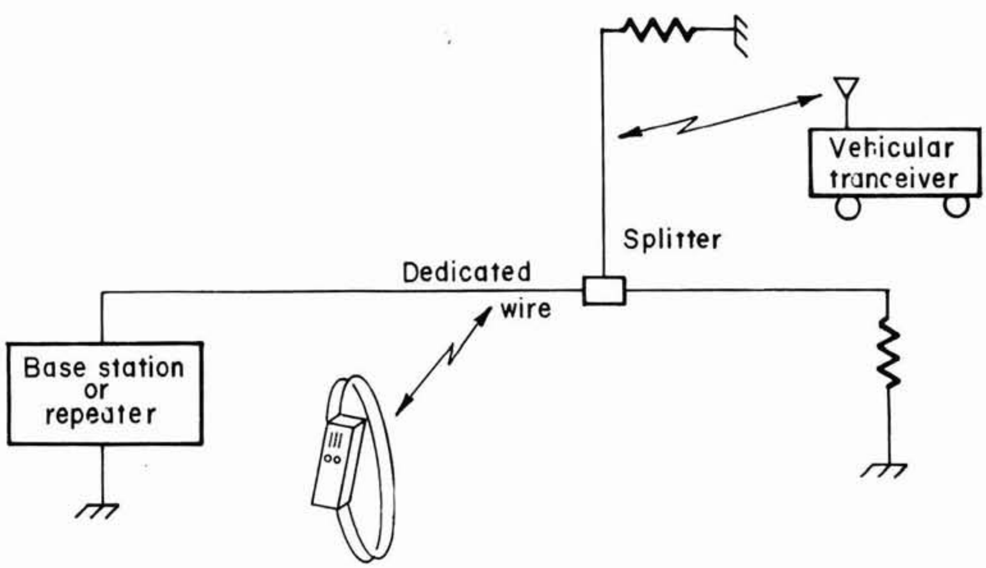

FIGURE 7.--Whole mine MF system using dedicated wires.

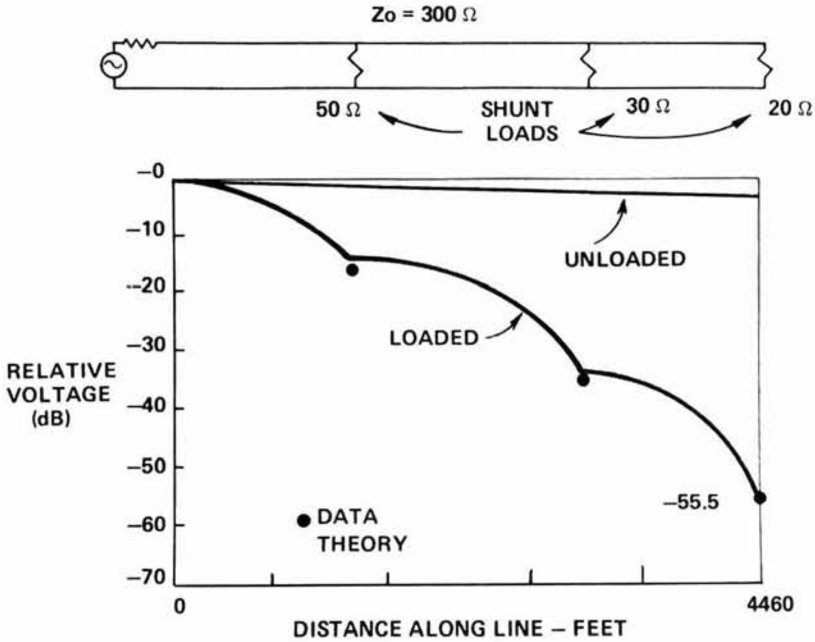

FIGURE 8.--Effects of loads on a simulated trolleyline.

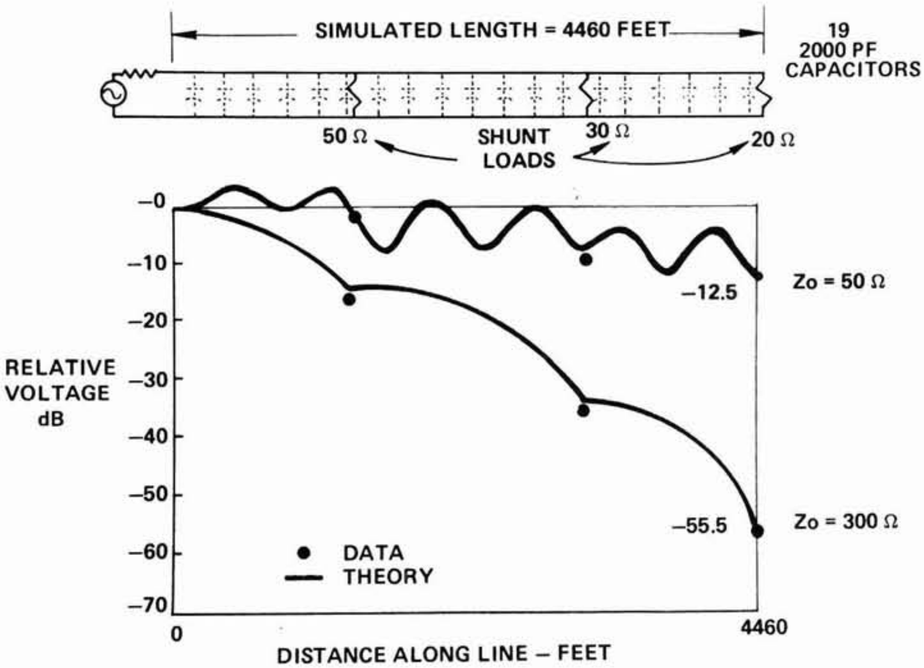

FIGURE 9.--Beneficial effects of reducing line characteristic impedance.